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Shallow depth of the tunnel excavation response research based on CRD method

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Abstract

Most bids of Dalian Metro are carried out with shallow tunneling method. However, for the section of Xianggong Street Station of Line 2, the geologic condition, which is mainly composed of strong-weathered rock, is so poor that it brings great difficulties in tunnel excavation. To solve the problem of stability of surrounding rock, numerical simulation and field monitoring are used to analysis the displacement field, stress field and plastic zone in every step of construction which use CRD method and also though the contrast of both consequence, The safety of the construction process has been studied and analyzed. The result not only has important guiding meaning after the construction of the tunnel, but also provides the reference for the design and construction of similar projects.

Keywords: tunnel engineering; excavation support; construction monitoring; 3D numerical simulation; excavation response

1. Introduction

For a long time, the design of the tunnel and underground engineering construction is mainly based on experience .But the process of the tunnel excavation supporting is a changing process of complex stress path, and the complicated variety of geological conditions and surrounding rock make things worse. So that solely rely on experience analysis is very difficult to release complex mechanical behavior. As the development of computing science and computer technology, three-dimensional numerical simulation can be used for quantitative calculation of the construction process of complex geotechnical engineering .

The geological conditions of the subway tunnel of the Dalian metro line 2,which is under construction, is complex and shallow. Above the tunnels is urban trunk road, and the traffic condition is complex and heavy, so the surrounding rock's stability problem is more obvious. Especially the controlling on the amount of ground settlement becomes important engineering problems in the construction process. This paper adopts three-dimensional geotechnical engineering software $FLAC^{3D}$ to analysis the construction process by numerical simulation, and combining the monitoring data of the construction to analysis the surface subsidence and vault sink, and evaluate the construction safety.

The station is about 28m depth, the thickness of the soil above the station is 6m, the station height

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between the top and bottom plates is about 15m, from the top down soil is as follows: plain fill, strongly weathered calcareous slate, calcareous slate weathered, shown in Fig 1.

Fig 1. The field construction

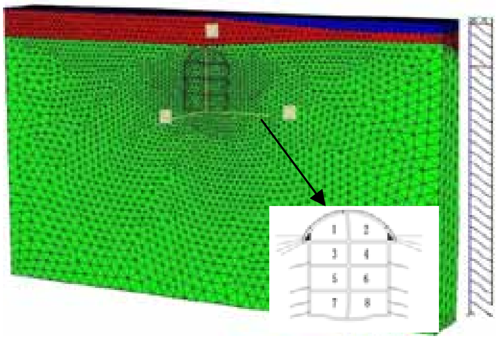

Fig. 2. Model of tunnel calculation and excavation sequence

2. Three-dimensional numerical simulation

2.1 The 3D model

This paper mainly simulates the process of tunnel construction, analyze the change of displacement, stress and plastic zone distribution. The calculation used for finite difference software FLAC^{3D}.according to the geological survey data, establish numerical model. This calculation scope selection for: The upper boundary take tunnel vaults to the ground about 6 m, height of the tunnel is 16m, from the lower boundary to tunnel floor is about 50 m. length of model is 12m. Level constraints exert an influence on the left and the right border, the lower boundary apply vertical constraint and The surface is free boundary. Calculation model is made up of 147921 units and 28021 nodes. The model is shown in Fig2.

2.2 The CRD construction process

Combining the construction methods and the actual situation, the CRD construction process simulation is as follows: (1) Around the tunnel boundary and the bottom is normal constraint and the surface is free boundary. Under the action of the own gravity, model first reaches initial stress equilibrium state. (2)applying driving load and excavate the first layer of left block (named figure 1 of the soil 1), solve the model after excavation, let it reach stress equilibrium state. And set the supporting structure, solve to reach stress equilibrium. (3)Excavating the soil two, three, four, five, six, seven, eight in turn, and set the first supporting structure respectively, then solve. The excavation process is shown in Fig2.

Mohr-Coulomb model is a quite successful and widely used constitutive model. In the *FLAC^{3D}*, the failure envelope for this model corresponds to a Mohr-Coulomb criterion (shear yield function) with tension cutoff (tension yield function). The position of a stress point on this envelope is controlled by a non-associated flow rule for shear failure and an associated rule for tension failure. The Mole - coulomb criterion correspondence's destruction enveloping curve is:

$$f_s=\sigma_1'-\sigma_3' N_\phi +2c\sqrt{N_\phi} \quad (1)$$

The N_Φ is :

$$N_\phi = \frac{1+\sin\phi}{1-\sin\phi} \quad (2)$$

The tensile strength criterion correspondence's enveloping curve is:

$$f_t = \sigma_t - \sigma_3' \quad (3)$$

In above formula: Φ is Angle of friction, C is Cohesive force, σ_t is Tensile strength.

Surrounding rock was assumed to be continuous media in the simulation calculation, its physical and mechanics parameters was performed by the engineering geological investigation data combined with standard. Physico-mechanical properties of rock, supporting structure materials is in Table 1.

Table 1. The physical and mechanical parameters of surroundings and supporting system

Parameter type	Elastic modulus /(MPa)	Poisson 's ratio	Angle of internal friction /(°)	Cohesion /(MPa)	Tensile strength /(MPa)	Density /(kg.m^{-3})
Plain fill	280	0.35	8	0.05	0.5	1.7
Strongly weathered slate	1500	0.3	24	0.3	10	2.2
Weathered calcareous slate	1800	0.28	28	0.345	10	2.7
Supporting structure	28000	0.35	–	–	–	–

3. Analysis of calculation results

3.1 The analysis of the displacement result of surrounding rock

Road above the station is the major urban traffic road, the physical and mechanical properties of rock is poorly. Under the circumstances,whether exerting driving load and tunnel support structure or not, tunnel excavation was calculated. tunnel ground subsidence trough curve respectively show in Fig 3. According to the numerical calculation results, Pavement driving load have a great impact on ground subsidence, and make rock produce large amounts of the overall sinking. Supporting structure decreased ground subsidence at the top of the tunnel, but have a little effect the overall sinking of tunnel surrounding.

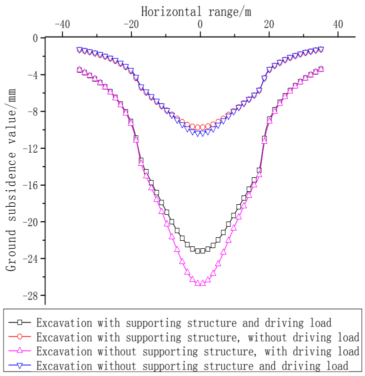

Fig. 3. The ground subsidence trough curve under different load and supporting conditions

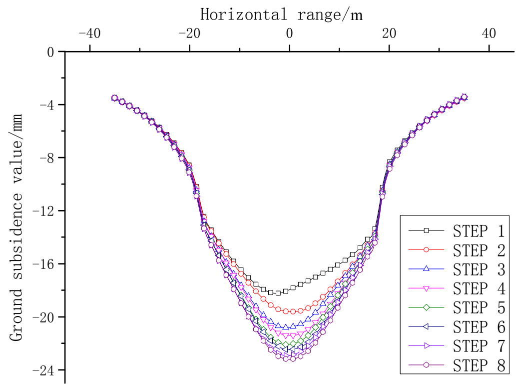

Fig. 4.The ground subsidence trough curve of each excavation time step

In the traffic load, the author analyze each time step of the excavation tunnel, make statistics of the displacement of ground subsidence, arch top settlement, headroom convergence, and summarize the rule of variety. The maximal displacement of surrounding rock during the each excavating time step. The ground subsidence caused by the first excavation step accounts for 78 per cent of the total ground subsidence, and the ground subsidence caused by the other excavation step is relatively rare, for this reason, reducing the first ground subsidence is important to decreasing the total ground subsidence. The displacement of arch top settlement equally distribute and is small in the each excavation step, accord with tunnel safety construction requirements. The displacement of headroom convergence is very small, supporting structure have very good lateral restraint function, the horizontal displacement is not the main factors which affect rock stability. The ground subsidence is the main influencing factors of dynamic construction, Fig4. Because excavation is not a symmetry process, the maximum displacement of the ground subsidence didn't appear among the model, instead slightly move to hollowed section. When excavation is completed, the maximum displacement is in the middle of the model.

3.2 Analysis the results of stress

The smallest stress isoline of each time step shows that, compressive stress mainly concentrates on the median septum of the initial supporting. In the process of the excavation downward the compressive stress of the median septum reach peak in the third step about 7.96 Mpa, then gradually smoothly decreases. And the maximum compressive stress of initial supporting is shown in Fig 5;Tensile stress has an obvious impact on transverse steel brace . During one side rock is excavated, the tensile stress of the lateral braces in the most lower level of another side increases markedly. It reaches maximum in the seventh time step, about 4.50 MPa, as figure 6 shows. The largest tensile stress releases during the excavation on the other side rock, and stress tends to evenly. median septum and transverse steel brace all use h-beam, yield point is 235MPa, tensile strength is about 375-460MPa. The surrounding rock stress distributed uniformly in every step when excavating, supporting structure has played a very good role of bearing the stress of the surrounding rock. The maximum compressive stress is about 3.56MPa; Tensile stress is concentrated on the bottom plate, and that the tensile stress is smaller, the maximum tensile stress is about 1.67 MPa. The greatest stress take effect on the surface near the excavation (Fig6).

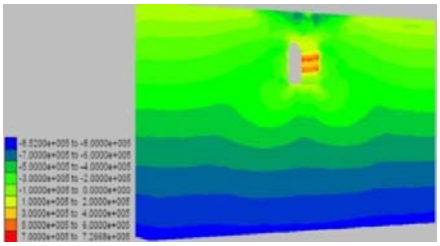

Fig5. The maximum compressive stress isoline diagram of surrounding rock after the last step excavation

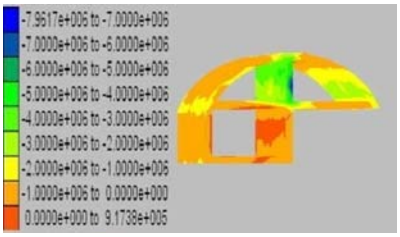

Fig 6. The maximum compressive stress isoline diagram of supporting structure

4. The results of contrast field monitoring with numerical analysis

Monitoring measurement in the construction is very important to accurate safe state of surrounding rock. According to the construction of Xianggong street station, we specially set up a monitor measuring group to dynamic monitoring displacement of the construction, so we can get information from it. Through to the work of acquisition and sorting monitoring data of the ground surface settlement, vaults sinking, with the most direct way to learn the safety of surrounding rock, and numerical simulation results were compared, monitoring stations in the position shown in Fig.7.

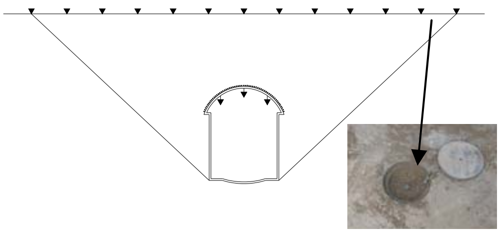

Fig7. Layout of on-site monitoring

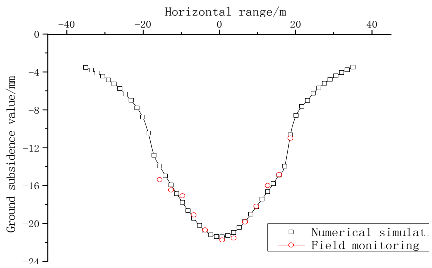

Fig8. Comparative diagram of surface subsidence trough at the fourth excavation

The station is still at stage of construction, construction schedule and the fourth excavation step of numerical simulation is consistent, sort out displacement value of each construction time step and compare with both. Figure 8 is the comparative diagram of the maximal displacement, from the first time step to the fourth after the excavation. When the fourth excavation is finished, comparative diagram of surface subsidence trough is shown in figure8, the results show that field monitoring displacement always coincide with numerical simulation, the numerical simulation results verify the rationality, also provides direct and real reference and basis for safe construction.

5. Conclusion

Based on the numerical simulation of the station and the long-term field monitoring, we get the following conclusion to refer reference experience for design and construction of similar projects in the future.

(1) The surface subsidence displacement in the first step of excavation produced the large proportion of total displacement .To buildings and bridges within the scope of the effect of construction, reinforcement measures is taken before excavation. Supporting in the construction and forming loading ring are very important during the excavation stage. Correct supporting conditions by combing construction monitoring data. Joint supporting of steel arch frame can be added and slow the construction schedule when necessary.

(3) Driving load in the construction area has a great impact on the around rock of the shallow-buried and undercutting tunnel .Meeting weak rock, the danger of collapse is easy to happen. To ensure that the traffic is safe above, open excavation or cover excavation can be taken into consideration. Initial supporting an obvious effect on plastic zone of surrounding rock, and the plastic zone is very small, without development trend. Tunnel stress condition is obviously improved, and tend to be evenly.

(4) Through the feedback analysis of monitoring data, we can verify the scientific and reasonable the design construction, and the feasibility of the construction method and supporting schemes, accurate adjusting support parameters timely, fix construction method and construction procedure, ensure construction safety.

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